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## Final report on the conference 'Geometric Methods for Infinite-Dimensional Dynamical Systems'

### Summary

The conference 'Geometric Methods for Infinite-Dimensional Dynamical Systems' was held November 4-6, 2011 at Brown University. It was jointly sponsored by the National Science Foundation, the Office of Naval Research, the Division of Applied Mathematics at Brown University, and the Department of Mathematics and Statistics at Boston University. The scientific organizing committee consisted of Sanjeeva Balasuriya (Connecticut College), Arjen Doelman (Leiden University, NL), Tasso Kaper (Boston University), Joceline Lega (University of Arizona), and Bjorn Sandstede (Brown University).

There were 81 registered participants. Most participants were from the US, but there were also foreign participants, including five from the UK, three from Canada, two from Japan, two from France, one from Germany, one from the Netherlands, one from Australia, one from the Czech Republic, and one from India. There were a number of participants from laboratories. Eighteen of the participants were women or members of traditionally underrepresented groups. The full list of participants is included at the end of this report. Registration was mandatory for all participants, but no registration fee was charged.

The 14 (long) plenary talks and the eight (short) topical talks were held in the lecture hall of the new NSF-sponsored Institute for Computational and Experimental Research in Mathematics (ICERM). The poster session was held in the spacious lobby area of the Barus and Holley building on campus, and it featured 16 posters. Other primary conference events included a panel discussion Saturday afternoon about open problems and important mathematical techniques, as well as a reception Friday evening, both of which were attended by all participants. The full conference schedule is included at the end of this report.

The conference website is <http://www.dam.brown.edu/people/sandsted/conferences/gmids-11.php>. All of the basic conference information has been posted there. The website also features the conference program, extended abstracts for all talks and posters, and pdf files of the talks.

### Scientific program

The plenary and topical talks formed the heart of the conference. They featured the four mathematical themes of the conference: data assimilation, geometric singular perturbation theory, nonlinear optics, and traveling waves.

Data assimilation for oceanographic flow problems and Navier-Stokes equations constituted a principal topic and received prominent attention from plenary speakers. Andrew Stuart (University of Warwick) presented novel filtering methods that he has been developing for understanding complex fluid flows and the Navier-Stokes equations. These filtering methods integrate experimentally obtained flow data with simulations of the model equations. The long-term goal of this work is to improve the predictions of climate simulations by integrating data, and the results presented in this talk are an important stepping stone toward this long-term goal. Larry Pratt (Woods Hole Oceanographic Institute, WHOI) presented state-of-the-art results about Lagrangian coherent structures, showing how the dynamical systems theory for invariant manifolds can be used to understand transport in real-world flows. He used data from off the coast of the Philippines. He also posed some open problems which highlight the challenges and opportunities for dynamical systems theory to make further contributions to this important field. George Haller (McGill University) presented an overview of how various concepts from dynamical systems theory, including finite time invariant manifolds, have been used recently to understand transport in oceanographic flows. He focused especially on barriers to transport in model geostrophic flows.

Sherry Scott (Marquette University) showed how the complexity of oceanographic flows can be measured using the ergodicity defect. Irina Rypina (WHOI) developed a similar theme, and demonstrated the efficacy of this approach on some real-world flows. Amit Apte (Tata Institute, India) presented results showing that data assimilation techniques need to be adapted for flows which involve nonlinear effects. Commonly-used data assimilation methods were developed primarily for linear flows, and he showed how these methods lose accuracy when nonlinear effects are strong. This is a wide open field of new research, with current focus on building up a theory for fundamental characteristics of nonlinear flows, including the presence of centers and saddles that Apte focused on. Elaine Spiller (Marquette University) also demonstrated the importance of improving data assimilation techniques for use on nonlinear flows.

These talks formed a coherent collection showing how our understanding of oceanographic flows and of the Navier-Stokes equations has improved through the use of data assimilation techniques, filtering, dynamical systems theory, and geometric methods for transport problems.

The second conference theme of geometric singular perturbation theory also received prominent attention from speakers. Nancy Kopell (Boston University) showed how the methods of geometric singular perturbation theory are advancing our understanding of the dynamics of mathematical models of brain rhythms and Parkinson's disease. These models exhibit dynamics on multiple time scales, and the fast-slow decomposition approach offered by geometric singular perturbation theory offers a powerful tool to analyze them. Jonathan Rubin (University of Pittsburgh) showed how geometric singular perturbation theory has been used in particle settling problems in fluid mechanics to analyze the likelihood of settling in certain flow fields. Martin Wechselberger (University of Sydney) is an expert in using the blow-up method, which is one of the most advanced components of geometric singular perturbation theory. In his talk, he demonstrated how the blow-up method can be used to determine the dynamics of transonic evaporation waves in certain nozzles. This work, which is joint with X.-B. Lin (NC State University), has resolved an important and long-standing problem in gas dynamics.

Invariant manifold are a central geometrical concept within theory of dynamical systems, given the strong emphasis on geometry that appeared throughout the entire conference, it's not surprising that there were three talks that focused entirely on this subject. Vadim Zharnitsky (University of Illinois) considered and explained the relevance of invariant manifolds in optimal search problems. Tassilo Kuepper (University of Cologne) studied center manifolds in non-smooth systems by several intriguing examples. Peter Bates (Michigan State University) presented results that he and his collaborators have obtained about invariant manifold theory for differential equations subject to stochastic perturbations.

Nonlinear optics constituted the third principal conference theme. Rudy Horne (Morehouse College) considered the stability of waves in certain optical devices and the effect of noise on pulse collisions. Tobias Schafer's (CUNY) presentation was focused entirely on the study of noise in nonlinear media and the (possible) reduction to finite-dimensional randomly perturbed dynamical systems. Alejandro Aceves (Southern Methodist University) studied various aspects of symmetries in periodic structures. Alan Lindsay (University of Arizona) went beyond the classical concept of nonlinear optics by studying buckling in a MEMS (Micro-Electro Mechanical Systems) capacitor, a device that may act as a switch at micro scales.

The fourth principal theme was traveling waves. This topic was featured broadly in many of the talks, including in the context of dissipative and conservative partial differential equations, and systems of interacting particles. The Evans function played in central role in many of the talks. Yuri Latushkin (University of Missouri) connected the Evans function to Fredholm determinants of Birman-Schwinger operators and to Weyl-Titchmarsh functions. Milena Stanislavova (University of Kansas) gave a general treatment of linear stability analysis for traveling waves in equations with double time derivatives in one spatial dimension. Yasumasa Nishiura (Tohoku University, Sendai, Japan) went beyond pure waves and studied, through a model for the locomotion of physarum, the interactions of waves with background effects (quinine in the case of physarum). Kevin Zumbrun (Indiana University) went beyond the linear analysis and presented his results establishing the nonlinear stability of periodic scroll waves in thin films on inclined surfaces. The collective behavior of interacting particles and rods -- the topic of Joceline Lega's (University of Arizona) presentation -- can be studied as the dynamics of patterns and waves in a hydrodynamic limit. However, it was the interplay between microscopic (particle interaction) models and their macroscopic effects that formed the core of her talk.

There was considerable overlap between the four main themes in several of the talks. For example, Rudy Horne's talk featured three of the conference topics: nonlinear optics, traveling waves, and geometric methods. Similarly, the subject of Jon Rubin's talk included three conference themes. It is also worth noting that stochastic effects in dynamical systems and applications played an important role in a series of the plenary and topical talks. Of course, understanding the effects of randomness is crucial in the context of data assimilation. But also Tobias Schafer (CUNY) considered the impact of noise on the transmission of optical pulses in media with nonlinear indices of refraction while Peter Bates (Michigan State University) studied the persistence of invariant manifolds under noise.

Within each of the main theme areas of the conference, the junior and senior mathematicians and scientists interacted substantially with each other. Several of the junior speakers told the organizers that this conference was an important and useful opportunity for them to present their latest results to the senior scientists and the wider audience, as well as to discuss ongoing research and open problems with each other.



The poster session, held late Friday afternoon, was an important event for all conference participants. Fifteen posters were presented, with the number of presenters being roughly equally balanced between junior and senior participants. The topics of the posters also spanned the four principal conference themes, with several of them covering multiple themes. Ample time (90 minutes) was devoted to the poster session, so that participants could circulate to all of the posters. Moreover, a reception was held in the same large space immediately following the poster session, so that participants could further their conversations about the research presented on the posters.

### Underrepresented groups

The conference also met the goal of attracting the participation of women and members of traditionally-underrepresented groups. Eight of the 22 plenary and topical speakers were women and/or members of traditionally-underrepresented groups.

### Funding

Financial support came from the NSF and from ONR. This funding was used according to the plan stated in the grant proposals. Ten of the 14 plenary speakers received partial reimbursement for their airfare and hotel. Many of the conference participants who presented posters also received reimbursement. Overall, approximately 50% percent of the funding was used for junior participants, including graduate students, postdocs, and tenure-track assistant professors. A detailed description of how the funds were distributed is given below, with junior participants indicated with an asterisk \*.

The following participants/speakers received support from the NSF grant:

Aceves	\$709.54	
Apte	\$429.51	*
Ghazaryan	\$761.95	*
Haller	\$524.42	
Humphries	\$715.95	
Kollar	\$297.50	*
Kuepper	\$620.00	
Law	\$327.00	*
Lega	\$429.51	
Lindsay	\$415.95	*
Liu	\$415.95	
Maultsby	\$369.59	*
Sharma	\$733.62	*
Stuart	\$415.95	
Sukhtayev	\$484.32	*
Wechselberger	\$1420.00	
Wu	\$415.95	*
Yan	\$477.23	*
Scott	\$429.51	*
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total:	\$10,393	

The following participants/speakers received support from the ONR grant:

Bates	\$349.30	
El Mograby	\$568.27	*
Jones	\$688.83	
Latushkin	\$429.51	
Law	\$326.36	*
Lin	\$306.34	
Manukian	\$421.80	*
McDougall	\$387.00	*
Pratt	\$464.54	
Rubin	\$146.45	

Rypina	\$438.54	*
Salman	\$1560.00	*
Spiller	\$534.60	*
Stanislavova	\$479.28	
Widiasih	\$638.10	*
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total:	\$9,611.88	

#### Registered conference participants

Alejandro Aceves	Southern Methodist University
James Alexander	National Science Foundation
Amit Apte	Tata Institute of Fundamental Research Centre
Sanjeeva Balasuriya	Connecticut College
Anna Barry	Boston University
Peter Bates	Michigan State University
Margaret Beck	Heriot-Watt University
Amit Bose	New Jersey Institute of Technology
Jared Bronski	University of Illinois
Tim Burns	NIST
Rodolphe Chabreyrie	Carnegie Mellon University
Carmen Chicone	University of Missouri
Graham Cox	University of North Carolina
Arjen Doelman	Leiden University
Amal El Mograbhy	North Carolina A&T State University
Anna Ghazaryan	Miami University
John Guckenheimer	Cornell University
George Haller	McGill University
Emily Harvey	Montana State University
Peter van Heijster	Boston University
Matt Holzer	University of Minnesota
Rudy Horne	Morehouse College
Tony Humphries	McGill University
Kayo Ide	University of Maryland
Russell Jackson	US Naval Academy
Jean-Michelet Jean-Michel	South Carolina State University
Christopher KRT Jones	University of North Carolina
Hans Kaper	Georgetown University
Tasso Kaper	Boston University
Todd Kapitula	Calvin College
Panayotis Kevrekidis	University of Massachusetts
Richard Kollar	Comenius University
Nancy Kopell	Boston University
Tassilo Küpper	University of Cologne
Yuri Latushkin	University of Missouri
Kody Law	University of Warwick
Joceline Lega	University of Arizona

Xiao-Biao Lin  
Alan Lindsay  
Weishi Liu  
Nan Lu  
Yi-Ping Ma  
Vahagn Manukian  
Bevin Maultsby  
Damon McDougall  
Richard Moore  
David Muraki  
Sri Namachchivaya  
Calistus Ngonghala  
Shunsaku Nii  
Yasumasa Nishiura  
Pascal Noble  
Alin Pogan  
Larry Pratt  
Keith Promislow  
Thomas Redd  
Andrew Roberts  
L Miguel Rodrigues  
Monica Romeo  
Vivi Rottschafer  
Jonathan Rubin  
Irina Rypina  
Rajarshi Saha  
Hayder Salman  
Bjorn Sandstede  
Naratip Santitissakedorn  
Tobias Schäfer  
Stephen Schechter  
Sherry Scott  
Vandana Sharma  
Elaine Spiller  
Milena Stanislavova  
Andrew Stuart  
Alim Sukhtayev  
Martin Wechselberger  
Esther Widiasih  
Qiliang Wu  
Dong Yan  
Chongchun Zeng  
Vadim Zharnitsky  
Kevin Zumbun

North Carolina State University  
University of Arizona  
University of Kansas  
University of Massachusetts  
University of Chicago  
Miami University  
University of North Carolina  
University of Warwick  
New Jersey Institute of Technology  
Simon Fraser University  
University of Illinois  
University of Tennessee  
Kyushu University  
Hokkaido University  
University of Lyon  
Indiana University  
Woods Hole Oceanographic Institution  
Michigan State University  
North Carolina A&T State University  
University of North Carolina  
University of Lyon  
  
Leiden University  
University of Pittsburgh  
Woods Hole Oceanographic Institution  
Bowdoin College  
University of East Anglia  
Brown University  
University of North Carolina  
CUNY  
North Carolina State University  
Marquette University  
University of Houston  
Marquette University  
University of Kansas  
University of Warwick  
University of Missouri  
University of Sydney  
University of Arizona  
University of Minnesota  
University of Massachusetts  
Georgia Institute of Technology  
University of Illinois  
Indiana University

## Conference schedule

Schedule	Friday 4 November
8:50-9:00 am	Welcoming remarks
9:00-9:35 am	Yasumasa Nishiura (Hokkaido University) Dynamics of localized patterns in dissipative systems
9:35-10:10 am	Joceline Lega (University of Arizona) Collective behaviors in two-dimensional systems of interacting particles and rods
10:10-10:40 am	coffee break
10:40-11:15 am	Andrew Stuart (University of Warwick) Filtering the Navier-Stokes Equation
11:15-11:50 am	George Haller (McGill University) A global theory of transport barriers
12:00-1:30 pm	lunch break
1:30-1:50 pm	Amit Apte (Tata Institute) Saddles and centers: effects of nonlinearity on data assimilation
1:50-2:10 pm	Irina Rypina (Woods Hole Oceanographic Institute) Investigating the connection between complexity of trajectories and Lagrangian coherent structures
2:10-2:30 pm	Sherry Scott (Marquette University) Ergodicity defect & analysis of ocean flows
2:30-3:00 pm	coffee break
3:00-3:20 pm	Alan Lindsay (University of Arizona) Multiple quenching solutions of a bi-harmonic PDE with singular nonlinearity
3:20-3:55 pm	Nancy Kopell (Boston University) Connecting the Dots: Propofol, Parkinson's Disease and Brain Rhythms
4:00-4:30 pm	break
4:30-5:30 pm	poster session (see last page) [Barus & Holley]
from 6 pm	reception [Barus & Holley]

Schedule	Saturday 5 November
9:00-9:35 am	Peter Bates (Michigan State University) Persistence of invariant manifolds under stochastic perturbation
9:35-10:10 am	Yuri Latushkin (University of Missouri) Birman-Schwinger operators and the Evans function in stability of traveling waves
10:10-10:40 am	coffee break
10:40-11:15 am	Rudy Horne (Morehouse College) Geometric methods and optical phenomena: An analysis of stability of wave solutions in certain optical devices
11:15-11:50 am	Vadim Zharnitsky (University of Illinois) Search on invariant manifolds
12:00-1:30 pm	lunch break
1:30-1:50 pm	Tassilo Küpper (University of Cologne) Center manifolds for nonsmooth systems
1:50-2:10 pm	Milena Stanislavova (University of Kansas) Linear stability analysis for travelling waves of the Boussinesq equation
2:10-2:30 pm	Kevin Zumbrun (Indiana University) Periodic Evans function analysis and stability of roll waves in inclined thin film flow

Schedule	Saturday 5 November
2:30-3:00 pm	coffee break
3:00-3:20 pm	Tobias Schäfer (CUNY) Effects of noise on pulses in cubic nonlinear media
3:20-3:55 pm	Alejandro Aceves (Southern Methodist University) Nonlinear Optics in periodic and PT-symmetric systems
4:00-4:30 pm	break
4:30-5:30 pm	panel discussion

Schedule	Sunday 6 November
9:00-9:35 am	Jonathan Rubin (University of Pittsburgh) Droplets and phosphorescence and steps, oh my!
9:35-10:10 am	Martin Wechselberger (University of Sydney) Transonic evaporation waves in a spherically symmetric nozzle
10:10-10:40 am	coffee break
10:40-11:15 am	Elaine Spiller (Marquette University) Assimilation for en route Lagrangian data
11:15-11:50 am	Larry Pratt (Woods Hole Oceanographic Institute) Chaotic advection in three dimensions

#### Poster session

- Amit Bose (New Jersey Institute of Technology)  
Dynamics on random graphs
- Jared Bronski (University of Illinois)  
Stability, synchrony, and geometry in the synchronization of coupled oscillators
- Anna Ghazaryan (Miami University)  
Traveling waves in a gasless combustion model with heat loss
- Matt Holzer (University of Minnesota)  
A slow pushed front in a Lotka-Volterra competition model
- Kody Law (University of Warwick)  
Filtering for the Navier-Stokes equation
- Xiao-Biao Lin (North Carolina State University)  
Construction and stability of standing waves for liquid/vapor phase transition in a spherically symmetric nozzle
- Weishi Liu (University of Kansas)  
Ion size effect on ion flows via Poisson-Nernst-Planck systems with density functional theory
- Yi-Ping Ma (University of Chicago)  
Homoclinic snakes bounded by a saddle-centre periodic orbit
- Vahagn Manukian (Miami University)  
On the traveling waves for the Gray-Scott model
- Amal El Mograbhy (North Carolina A&T State University)  
A stopping time criteria for computing Lagrangian structures
- Richard Moore (New Jersey Institute of Technology)  
Matched asymptotics of traveling waves in nonlocal damped and dispersive equations
- Shunsaku Nii (Kyushu University)  
Bifurcations of stationary solutions with triple junctions in phase separation problems
- Calistus Ngonghala (University of Tennessee)  
Extreme multi stability in a chemical model system
- Rajarshi Saha (Bowdoin College)  
Relaxation oscillations in the thermohaline circulation due to sea ice processes
- Qiliang Wu (University of Minnesota)  
Dynamics near Turing patterns in RD systems